

PAST TRENDS IN PROCUREMENT OF AIR INTERCEPT MISSILES
AND IMPLICATIONS FOR THE ADVANCED MEDIUM-RANGE
AIR-TO-AIR MISSILE PROGRAM (AMRAAM)

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PREFACE

The U.S. Navy and Air Force have been developing and procuring guided missiles to be used by aircraft to attack other aircraft for more than three decades. In recent years, there has been concern in the Congress that increasing costs of these Air Intercept Missiles may be jeopardizing the ability of the services to procure sufficient quantities. Currently, much of this concern is focused on the Advanced Medium Range Air-to-Air Missile (AMRAAM), which entered full-scale development in early 1982.

The Research and Development Subcommittee of the House Committee on Armed Services has requested this CBO study of topics related to the development and procurement of Air Intercept Missiles in order to aid that Subcommittee in deciding about the future of the AMRAAM program. This paper, which examines the history of procurement of AIM systems, is a partial fulfillment of that request. This study was undertaken to ascertain what lessons, if any, could be derived from history which would be useful to the Congress in judging AMRAAM. In accordance with CBO's mandate to provide objective and impartial analysis, the paper offers no recommendations.

The paper was prepared by Alan H. Shaw of CBO's National Security and International Affairs Division, under the general supervision of Robert F. Hale and John J. Hamre. It was reviewed by Dr. John Transue and received internal CBO review. The cooperation of the U.S. Navy and Air Force in supplying data is gratefully acknowledged. The assistance of external reviewers and of the Air Force and Navy implies no responsibility for the final product, which rests solely with CBO. Francis Pierce and Robert Faherty edited it; Janet Stafford typed it.

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SUMMARY

Soon after World War II, the Navy and the Air Force began development of guided missiles to be used by fighter aircraft in attacking other aircraft. Compared with the guns used by fighters up until that time, such air intercept missiles (designated AIM) offer greater range, greater accuracy, and the opportunity to engage an enemy aircraft over a greater range of relative positions. Although air intercept missiles entered the inventory too late to be used in the Korean War, they were used extensively in the Southeast Asian conflict. This paper examines the history of AIM procurement in order to provide a framework to aid the Congress in making decisions concerning the Advanced Medium Range Air-to-Air Missile (AMRAAM), currently under development.

INTRODUCTION TO AIR INTERCEPT MISSILES

Beginning in the mid-1950s, the Navy introduced two families of missiles, the AIM-9 Sidewinder and the AIM-7 Sparrow, and the Air Force produced the Falcon missile (designated AIM-4 and later AIM-26). In the 1960s, the Air Force began to buy Sidewinders and Sparrows, and terminated Falcon production. In 1971, the Navy initiated procurement of the long-range AIM-54 Phoenix missile. The Phoenix, Sparrow, and Sidewinder remain in production, the latter two having undergone several model changes.

The Sidewinder is carried on all currently operational U.S. Air Force, Navy, and Marine Corps fighters and interceptors. With a maximum range of about four miles, it is the principal weapon for engagements within visual range. The missile homes on the infrared emissions of the target aircraft. The missile seeker acquires the target prior to launch; once launched, the missile is independent of the launch aircraft. The 25-year evolution of the Sidewinder has resulted in numerous improvements. The principal ones have been increased seeker sensitivity to allow the missile to detect the target from any angle (all-aspect capability), the ability to detect a target not directly in front of the launch aircraft (off-boresight capability), and greater capability to detect the target in the presence of other infrared signals (operations in clutter). The major limitations of the Sidewinder are its range and the degradation of seeker performance under certain weather conditions.

Engagement range is extended by the 25-mile Sparrow carried on F-4, F-14, F-15, and F/A-18 aircraft. The Sparrow is a beyond-visual-range missile that homes on the radar signal broadcast by the launch aircraft and reflected from the target. Operating the Sparrow requires the pilot to illuminate the target continuously with his radar from the time the missile is launched to the time of impact. Like the Sidewinder, the Sparrow has gone through a progression of model improvements since it was introduced in 1957.

The long-range Phoenix missile (maximum engagement range about 100 miles) is carried only on the Navy's F-14. For part of its flight, the Phoenix is guided the same way Sparrow is. For the last part of its flight, however, it uses its own on-board radar for guidance, freeing the launch aircraft from further interaction with the missile. This active terminal homing, plus features of the F-14 radar, allow the F-14 to engage several targets simultaneously

Experience has shown that there are some fundamental problems associated with operating the Sparrow that stem primarily from its mode of guidance. Operating the Sparrow restricts the flight path of the pilot during missile flight, making him vulnerable to counterattack by his target or by another aircraft. A pilot attacking a target can fire several Sparrows at that target, but cannot engage another target while his attack is still in progress. Finally, the Sparrow is not compatible with the F-16, which will be the most numerous U.S. fighter.

In order to overcome these deficiencies, the Air Force and Navy have been developing a new Advanced Medium Range Air-to-Air Missile as a successor to the Sparrow. AMRAAM will employ active terminal homing similar to that used on the Phoenix to allow it to operate autonomously after launch. It will be operational on all modern U.S. fighters and interceptors: F-14, F-15, F-16, F/A-18. The Phoenix itself would not be a viable substitute for the Sparrow since it is twice the weight and about six times the cost of the Sparrow, and requires a very costly radar on the launch aircraft in order to achieve long-range performance.

AMRAAM entered full-scale development in early 1982, and is expected to enter production in the mid-1980s. The current program calls for an \$800 million development program followed by the production of 20,000 missiles at \$190,000 each (in fiscal year 1982 dollars), approximately one-half more than the unit cost of the most recent Sparrow model, AIM-7M.

SCOPE

Progressive improvements in AIMS have been accompanied by significant increases in unit costs. There has been concern in the Congress that, no matter how effective AMRAAM is, it may be ultimately too costly to buy in the quantities necessary to supply U.S. forces adequately. Congressional decisions regarding AMRAAM will be made against the backdrop of several widely held perceptions. These are:

- o As time has progressed, the procurement of AIMS has consumed an increasing share of the defense budget while the number procured has decreased;
- o Actual unit costs of AIM systems are always much more than initial estimates;
- o This has led to difficulties in achieving inventory goals.

The implications of these hypotheses for AMRAAM seem clear: if they are true, the actual unit cost of AMRAAM will be much greater than that of the Sparrow, either increasing the impact of AIM procurement on the defense procurement budget, slowing progress toward reaching inventory goals, or both. This paper uses the history of AIM procurement to test these hypotheses and to ascertain what can be learned from history that may be useful to the Congress in judging the AMRAAM program. In particular, the paper examines:

- o Long-term trends in the number of AIMS procured and the impact of that procurement on the defense procurement budget;
- o The pattern of changes in the estimated costs of AIM systems as they have proceeded through full-scale development and into procurement.

LONG-TERM PROCUREMENT TRENDS

Contrary to some perceptions, DoD has not been devoting an ever increasing share of its procurement dollar to a diminishing number of AIMS. While it is true that compared to the early years of AIM procurement DoD is spending about the same fraction of its budget for one-fourth as many missiles, since about 1970 both

numbers and budget share have increased at about the same rate. During the 1960s, the cost of missile improvements was absorbed by buying fewer missiles, while during the 1970s it was accommodated by increasing the budget share devoted to AIMS. This is illustrated in Summary Figure 1. In addition, the budget share allotted to procuring the Sidewinder and the money allotted for the Sparrow (not shown in the figure) have individually followed the same general trend as the aggregate.

Two main causes underlie the divergence of the trends in numbers and costs. First, the constant-dollar unit cost of the AIM-9 Sidewinder, which has usually been procured in greater numbers than the AIM-7 Sparrow, increased fivefold from the early 1960s to the late 1970s. Second, there has been a gradual shift toward buying fewer Sidewinders and proportionately more Sparrows. The Sparrow missile, although its cost has been more nearly constant over time, has always been more expensive than the Sidewinder. In addition, the introduction of the very costly AIM-54 Phoenix is responsible for a large share of cost growth, as indicated in the figure.

If a long-term linear trend can be discerned over the more than two decades that AIMS have been procured, on the average, the impact on the defense budget of expenditures for AIM procurement has been roughly constant. If history is any guide, the budget share devoted to AIMS is not likely to change much in the near future. Therefore, cost control in AMRAAM becomes an important consideration.

GROWTH IN DEVELOPMENT AND PROCUREMENT COSTS

While history cannot predict the future costs of AMRAAM, it can yield an important perspective. Cost growth in development and procurement for six air intercept missile programs (AIM-7E, AIM-7F, AIM-7M, AIM-9L, AIM-9M, AIM-54A), as reported in constant dollars in the Defense Department's Selected Acquisition Reports (SARs), has been analyzed and compared to growth for all the programs reported in recent SARs. Growth in development cost is of interest both of itself and because of its possible utility as an indicator of procurement cost growth.

Development Cost Growth

Development cost growth for these six AIM systems followed a rather irregular pattern. Three showed no growth; two showed

extremely high growth of 300 percent to 400 percent, which is seven to ten times the average for all the systems reported in recent SARs (that is, 40 percent); and one (AIM-54A) grew at just over the average rate for all current SAR systems. The two that showed very high growth represented, in general, greater technical departures from their predecessors than did those that showed no cost growth, while the AIM-54A program developed an entirely new missile--clearly a technical departure.

The data suggest a pattern with implications of AMRAAM, but are not conclusive. Development cost growth is qualitatively correlated with degree of technical departure. One possible interpretation of the data is that the cost of AIM developments that involve important technical departures, such as AMRAAM, are wildly unpredictable. Another is that the cost of such developments are likely to be several hundred million dollars, as AIM-7F, AIM-9L, and AIM-54A were, and that the AMRAAM estimate of \$800 million for development is likely to be a realistic one. The data provide no statistical basis for choosing one interpretation over the other. While the AIM-54A program seems closest to AMRAAM based on degree of technical departure and the magnitude of the initial estimate of development costs, a single data point has no statistical significance.

Unit Cost Growth

Unlike development cost growth, the growth in unit cost for the originally planned quantities of the six systems was distributed in a manner consistent with all current SAR systems. The lowest growth in unit cost of the AIM systems was 10 percent and the highest was 90 percent; the average of 43 percent is very close to the average for all SAR systems. The fact that the unit cost increases displayed by so many systems follow a fairly well-defined distribution indicates a reasonable likelihood that future programs will follow the same pattern. Without a detailed understanding of the mechanisms that produce this cost growth, it is not possible to predict what the growth of any particular system will be.

Furthermore, there is an apparent correlation between unit cost growth and development cost growth. The average unit cost growth for the three systems with no development cost growth was 28 percent, while the average for the other three was about 56 percent. An examination of all systems in the current SARs as well as the historical AIM data indicates that unit cost increases

are generally correlated with development cost increases. Indeed, it can be generally concluded that increases in development cost almost always mean increases in unit cost, though a lack of increase in development cost does not guarantee low unit cost increase. Development cost growth appears to be an indicator of unit cost growth to come.

The unit cost growth of systems with the same development cost growth typically shows a wide variation, however, making a precise numerical prediction of one from the other fairly meaningless. While the data do not support an accurate prediction of unit cost growth from development cost growth, the data are more strongly supportive of a minimum value of unit cost growth as a function of development cost growth. The data strongly support a minimum value of unit cost growth of 25 percent or half of development cost growth, whichever is lower.

The data confirm intuitive expectations. Since the earliest estimates of development and procurement costs published in a SAR are made at the same time, whatever factors operate to produce a low estimate of one would be expected to produce a low estimate of the other. The competition for funds provides an incentive to err on the low side of the region of uncertainty of both estimates.

IMPLICATIONS FOR AMRAAM INVENTORIES

History presents no hard and fast conclusions that can be applied directly to AMRAAM. It does, however, provide a useful framework for examining the program.

On the basis of historical precedent, AMRAAM is a good candidate for growth in both development cost and unit cost, but history provides no firm prediction that AMRAAM costs will grow. Based on past experience with AIMS and current SAR systems, unit cost growth on the order of 50 percent would not be surprising. Unit cost growth of less than 10 percent or more than 100 percent would be surprising, but is certainly not impossible. As time progresses, it may be possible to form a better judgment of what unit costs are likely to be by monitoring the development program.

There are currently shortfalls in inventories of both Sidewinders and Sparrows, especially in the later models. There has been concern in the Congress about the rate at which the inventory objectives for the newest missiles, especially the AIM-7M, will

be approached. If past patterns of funding continue in the future, AMRAAM, which is currently estimated to cost about 50 percent more than AIM-7M, would be procured at rates less than or equal to its predecessor. If AMRAAM unit costs are ultimately significantly greater than currently predicted, either the impact of AIM procurement on the defense budget will have to be increased beyond what it has traditionally been, or AMRAAM will have to be procured at a lower rate than the AIM-7M it is due to follow. In this regard, it is important to note that reductions in buy rates below those planned in a program cause further cost increases and yet further rate reductions.

In making decisions regarding AMRAAM, other important factors need to be considered. The program is not being pursued in a vacuum. The program management has 25 years of service experience in developing AIMS and other missiles to draw upon, and has introduced several management initiatives to control development and production costs. Finally, cost is not the only factor in procuring defense systems. If the system is really needed, its procurement should be seriously considered despite any cost problems which may arise. In doing so, however, the Congress (and DoD) ought to keep in mind that significantly increased costs and constant or rising inventory objectives cannot be easily accommodated within a relatively constant share of the budget, and that procuring a system under these circumstances will have important implications for the rate at which it is procured and the funds available for other defense procurement.

CHAPTER I. INTRODUCTION

The U.S. Navy and Air Force have been developing and procuring air-to-air missiles for about 30 years. These missiles, which carry the designation AIM for air intercept missile, are designed to be launched from an airplane in order to destroy another airplane, thereby extending the engagement range of the launch aircraft beyond the effective range of its gun.

As the complexity and operational capabilities of these missile systems have increased, costs have also increased leading some in the Congress and within the Department of Defense (DoD) to express concern that rising unit costs could, in the near future, jeopardize the maintenance of sufficient inventories. A particular reason for concern is that a new missile system differing in design from its predecessors in some fundamental ways is entering full-scale development, and cost growth in the future could make it prohibitively expensive.

As a practical matter, the Congress will have to decide on a year-to-year basis whether or not to fund continued development of this Advanced Medium Range Air-to-Air Missile (AMRAAM). The decision will be based in part upon how the Congress views the likelihood that the program will meet its cost and performance goals.

The AMRAAM development program is estimated to cost \$800 million. About \$200 million has been appropriated through 1982 and \$212 million is requested for 1983. The current plan is to buy 20,000 missiles at an average of \$190,000 each (in fiscal year 1982 dollars), beginning in the latter half of the 1980s. AMRAAM is a joint Air Force/Navy program, with the Air Force as lead agency.

SCOPE

This report provides a historical perspective within which the costs of AMRAAM may be judged. In particular, it presents long-term trends in costs and numbers of missiles procured, and a brief analysis of growth in their development and production costs.

After a brief history of AIM developments presented in Chapter II, Chapter III examines long-term trends in the number of air intercept missiles procured, the fraction of the DoD procurement budget devoted to that procurement, and unit costs. This analysis was conducted in order to examine the contention that over the years DoD has been spending increasing amounts on air intercept missiles, but has been getting fewer of them. The analysis also provides an understanding of how changing costs associated with successive model improvements have been accommodated in the past, and a context within which to judge what may happen if the AMRAAM costs significantly more to procure than its predecessors.

Chapter IV analyzes past cost growth during selected missile programs. This analysis makes no projection of AMRAAM cost growth, but provides a framework within which an informed judgment may be made regarding possible cost growth as the program progresses through full-scale development into procurement.

The paper examines only topics related to costs and cost growth. Whatever the ultimate cost performance of the AMRAAM program, decisions to proceed with development and procurement will also depend upon the capabilities of the system, the availability and relative attractiveness of alternatives, and, on balance, its contribution to U.S. defense capabilities.

CHAPTER II. BACKGROUND

During World War II, fighter aircraft attacked enemy aircraft exclusively with guns. In the late 1940s, the U.S. Air Force and Navy initiated the development of air-to-air guided missiles that would provide aircraft with weapons of substantially greater range than the gun. In the mid-1950s, the Navy began production of the short-range AIM-9 Sidewinder, an infrared homing (heat seeking) missile, and the medium-range AIM-7 Sparrow, which employs semi-active radar homing. 1/ These two missiles are still in production, having undergone numerous modifications in the intervening years. From 1954 to 1963, the Air Force produced the Falcon missile (designated AIM-4 and AIM-26), in both infrared and semi-active radar models. 2/

Since the mid-1960s, Sidewinder and Sparrow have been employed by both services and by many foreign nations. In addition, the Sparrow is employed from a shipboard launcher as the RIM-7 Sea Sparrow, and a variant of the Sidewinder is used in the Army's Chaparral surface-to-air missile system. 3/

The Sidewinder is carried on all currently operational U.S. Air Force, Navy, and Marine Corps fighters and interceptors. With a maximum range of about four miles, it is the principal weapon for engagements within visual range. The missile homes on the infrared emissions of the target aircraft. The missile seeker acquires the target prior to launch; once launched the missile is independent of the launch aircraft. The 25-year evolution of the Sidewinder has resulted in numerous improvements as shown in Figure 1 and Table 1. The principal ones have been: increased seeker sensitivity to allow the missile to detect the target from any angle (all-aspect capability), the ability to detect a target

1/ The launch aircraft illuminates the target with its radar, and the missiles home on the energy reflected from the target.

2/ This period also saw the production of unguided air-to-air weapons, which are not discussed in this report.

3/ Neither Sea Sparrow nor Chaparral is included in this study.

FIGURE 1. SIDEWINDER MISSILE HISTORY

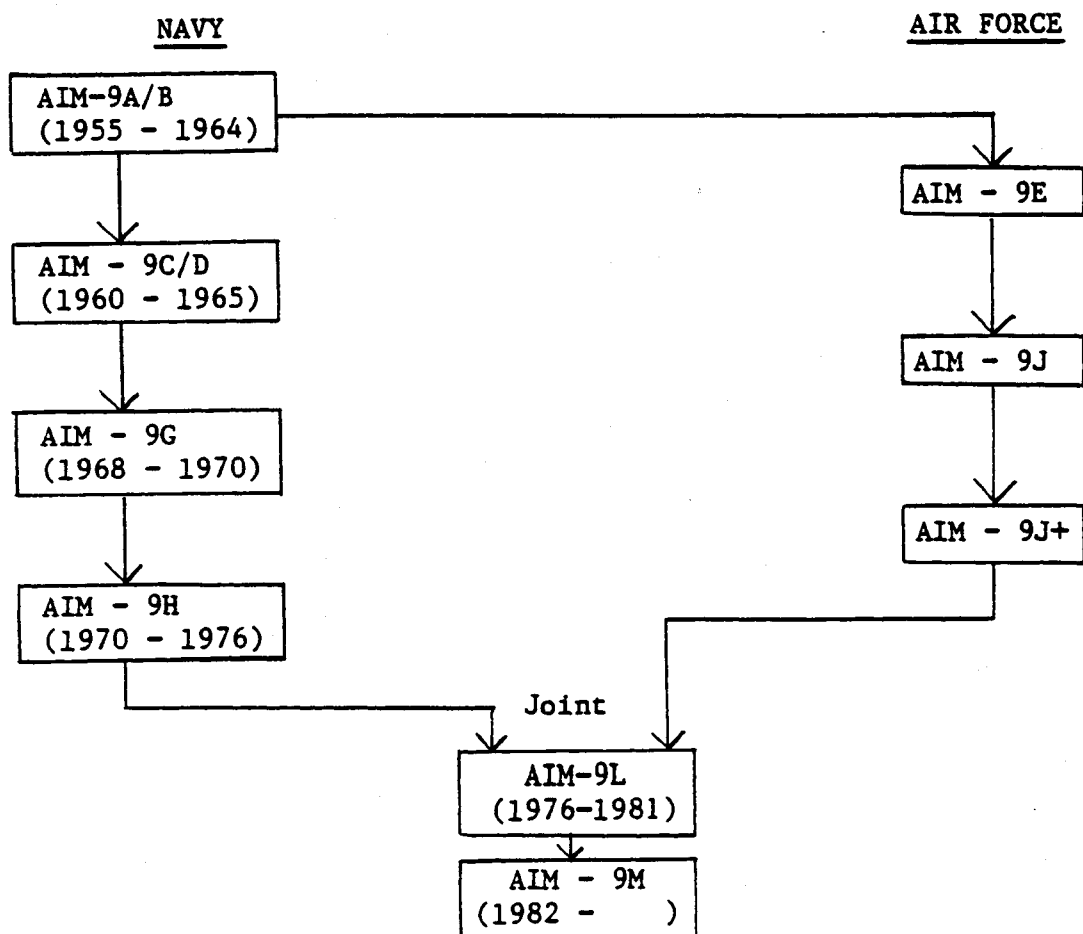


TABLE 1. THE SIDEWINDER MISSILE

Model	Major Changes from Earlier Models
AIM-9A	Prototype.
AIM-9B	First production model.
AIM-9C	Semi-active radar version of AIM-9B (only SAR AIM-9).
AIM-9D	Higher speed; greater range.
AIM-9E	Modification of AIM-9B for USAF: improved seeker for better low altitude performance.
AIM-9G	Off-boresight target acquisition.
AIM-9H	Better close-range "dogfight" capability; solid state electronics.
AIM-9J	Conversion of AIM-9B/E for better "dogfighting," better maneuverability.
AIM-9P (or JP)	Improved AIM-9J.
AIM-9L	Developed for "dogfighting": increased seeker sensitivity for all aspect target acquisition; greater maneuverability.
AIM-9M	Improved performance in presence of counter-measures and clutter; reduced smoke motor.

SOURCES: Jane's Aircraft 1980-81, Jane's Weapon Systems 1980-81, Jane's Weapon Systems 1979-80.

not directly in front of the launch aircraft (off-boresight capability), and greater capability to detect the target in the presence of other infrared signals (operations in clutter). The major limitations of the Sidewinder are its range and the degradation of seeker performance due to certain weather conditions.

Engagement range is extended by the 25-mile Sparrow carried on F-4, F-14, F-15, and F/A-18 aircraft. The Sparrow is a beyond-visual-range missile that homes on the radar signal broadcast by the launch aircraft and reflected from the target. Operating the Sparrow requires the pilot to illuminate the target continuously with his radar from the time the missile is launched to the time of impact. Like the Sidewinder, the Sparrow has gone through a progression of model improvements since it was introduced in 1957, as shown in Tables 2 and 3.

TABLE 2. SPARROW MISSILE HISTORY

Model	Approximate Production Dates	User
AIM-7C	1957 - 1959	USN
AIM-7D	1959 - 1962	USN/USAF
AIM-7E	1963 - 1970	USN/USAF
AIM-7E2	1969 - 1973	USN/USAF
AIM-7F	1974 - 1982	USN/USAF
AIM-7M	1982 -	USN/USAF

TABLE 3. THE SPARROW MISSILE

Model	Major Changes from Earlier Models
AIM-7C,D,E AIM-7E2	Basic Sparrow semi-active radar missile. Better maneuverability for improved "dogfighting."
AIM-7F	Solid state electronics, larger motor for greater range and speed, greater reliability and lethality, increased launch and attack volumes, and improved lock-on in presence of look-down clutter.
AIM-7M	Improved seeker for better performance in presence of countermeasures and look-down clutter.

SOURCES: Jane's Aircraft 1980-81, Jane's Weapon Systems 1980-81, Jane's Weapon Systems 1979-80, Air Force Magazine (May 1981).

The long-range Phoenix missile (maximum engagement range about 100 miles) is carried only on the Navy's F-14. For part of its flight, the Phoenix is guided the same way the Sparrow is. For the last part of its flight, however, it uses its own on-board radar for guidance, freeing the launch aircraft from further interaction with the missile. This active terminal homing, plus features of the F-14 radar, allow the F-14 to engage several targets simultaneously.

Experience has shown that there are some fundamental problems associated with operating the Sparrow, stemming primarily from its mode of guidance. Operating the Sparrow restricts the flight path of the pilot during missile flight, making him vulnerable to counterattack by his target or by another aircraft. A pilot attacking a target can fire several Sparrows at that target, but cannot engage another target while his attack is still in progress. Finally, the Sparrow is not compatible with the F-16, which will be the most numerous U.S. fighter.

In order to overcome these deficiencies, the Air Force and Navy have been developing a new Advanced Medium Range Air-to-Air Missile as a successor to the Sparrow. AMRAAM will employ active terminal homing similar to that used on the Phoenix to allow it to operate autonomously after launch. It will be operational on all modern U.S. fighters and interceptors: F-14, F-15, F-16, and F/A-18. The Phoenix itself would not be a viable substitute for the Sparrow since it is twice the weight and about six times the cost of the Sparrow, and requires a costly radar on the launch aircraft in order to achieve long-range performance.

CHAPTER III. HISTORICAL TRENDS IN MISSILE COSTS AND QUANTITIES PROCURED

This chapter examines trends exhibited over the past three decades in the costs of air-to-air missiles and in the numbers procured. While the most relevant data are for the past ten years (1973-1982), those for earlier years lend important perspective, as the figures will show. The data from 1973 forward are complete; the earlier data are not. In particular, data for Sidewinder models produced exclusively for the Air Force by modifying existing missiles (AIM-9E, AIM-9J, and AIM-9JP) were not available from the Air Force. All Navy procurement and all Air Force Sparrow procurement appears to be accounted for in data supplied by the program offices. Future projections are also based upon program office data, corroborated and augmented by other sources. In the case of some of the early models, total costs have been calculated from partial or complete hardware costs by applying scaling factors derived from more modern models.

AGGREGATE TRENDS FOR TOTAL AIM PROCUREMENT

Numbers Procured

Figure 2 shows the number of air intercept missiles bought each year from 1973 to 1982, with projections to 1986 (based on program office estimates). A steady decrease in 1979-1981 is evident, with a planned correction in the near future as the M models are procured. However, this decline follows a much longer increase beginning in the early 1970s. Therefore, the seemingly sharp decline is actually a temporary and relatively small fluctuation following a long rise.

Figure 3 shows the same information extending back to 1954. From this, it is clear that the early 1970s represented the culmination of a period of tremendous decline that began about ten years earlier, a decline only partially reversed by the steady increase which followed. Even allowing the removal of Falcon from the total buy, the decrease in AIM-7 and AIM-9 procurement was a factor of roughly 10. The Phoenix accounts for only a small fraction of the total buy, and its inclusion does not affect the general trends.

FIGURE 2. THE NUMBER OF AIR INTERCEPT MISSILES PROCURED EACH YEAR

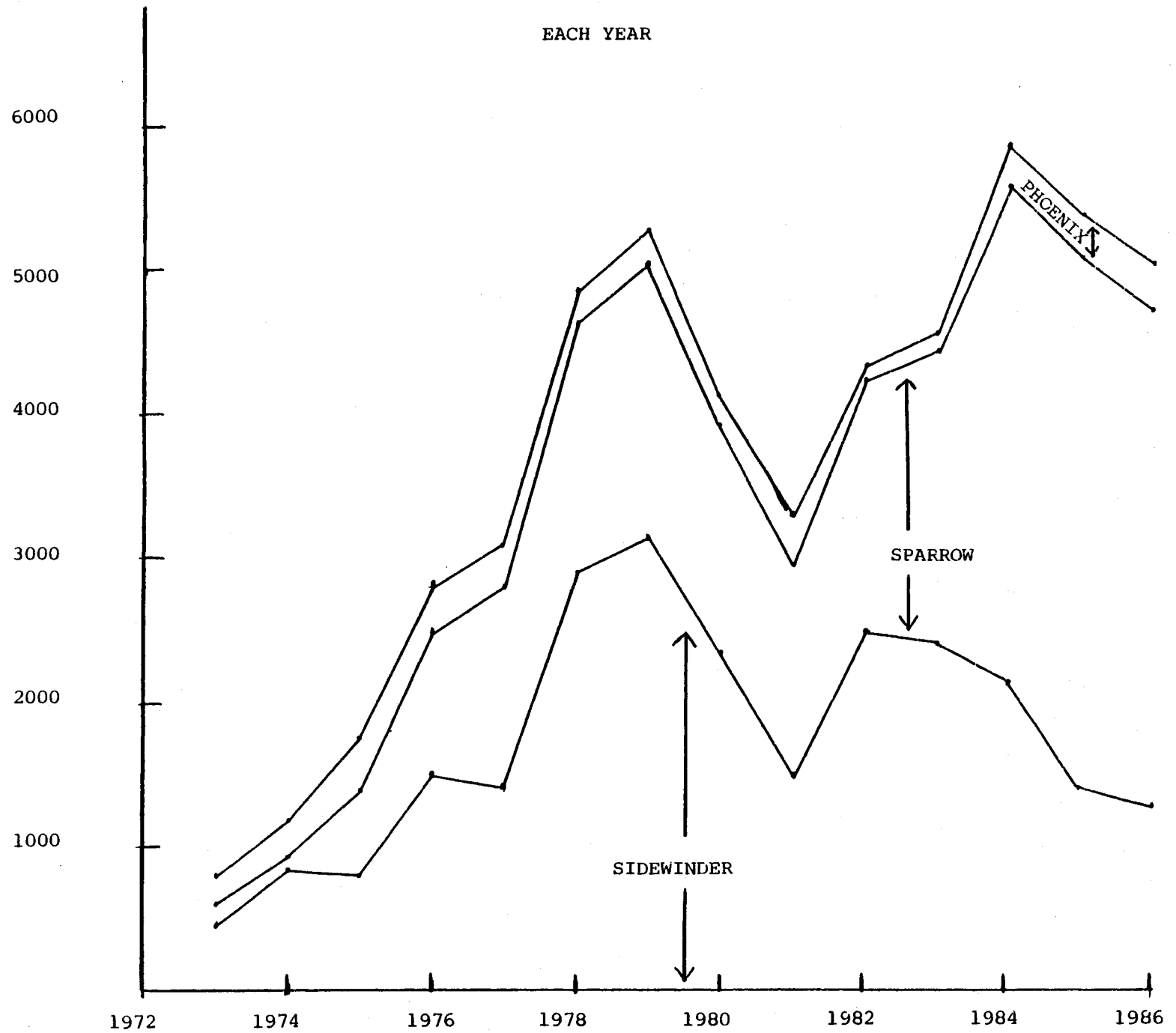
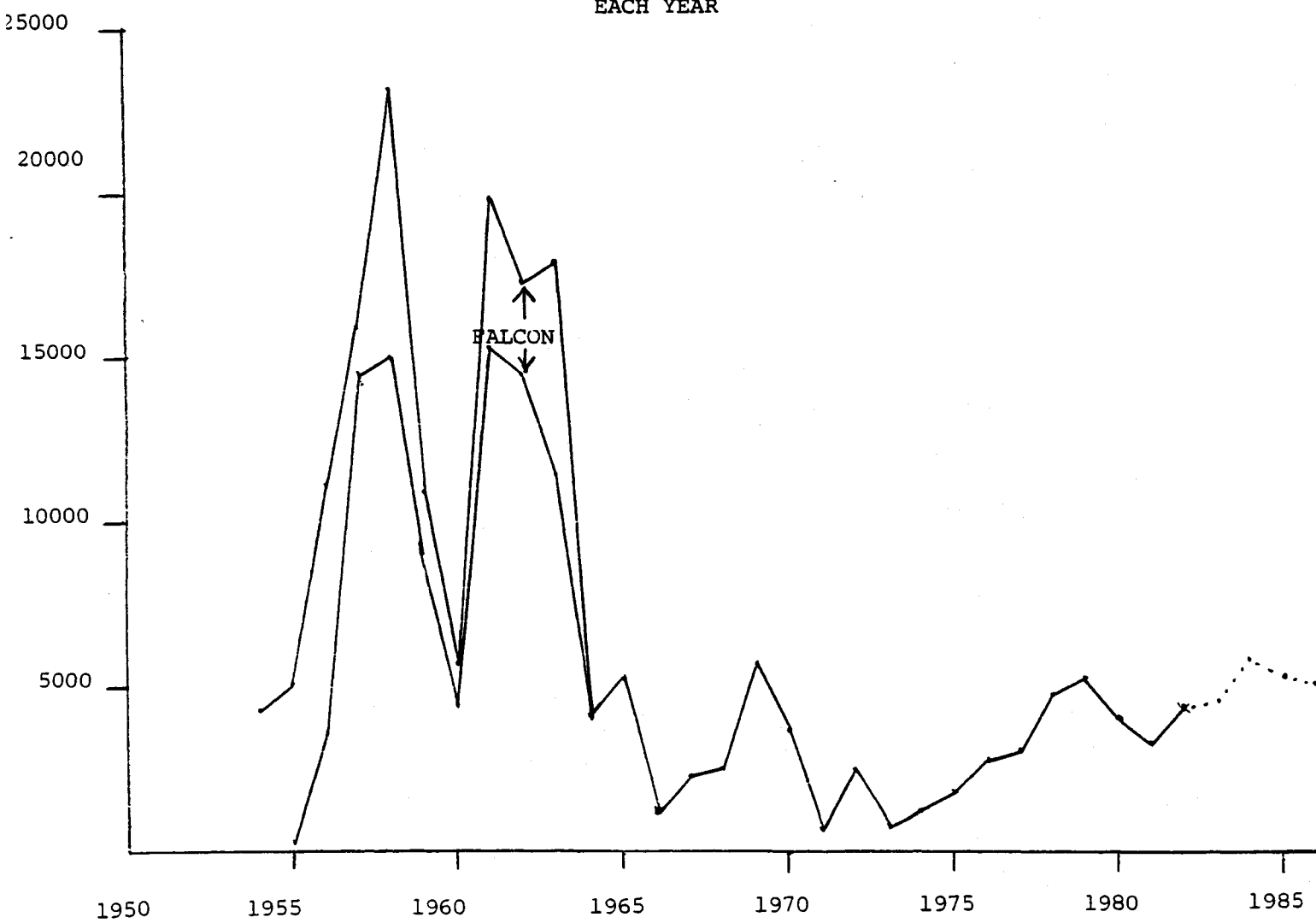


FIGURE 3. THE NUMBER OF AIR INTERCEPT MISSILES PROCURED
EACH YEAR



Between the mid-1960s and the late 1970s, about 5,000 Air Force AIM-9Bs were modified to become AIM-9Es, and were subsequently remodified along with 9,000 more AIM-9Bs to the AIM-9J configuration. Inclusion of these modifications in Figures 2 through 4 will alter the data in detail, but not the trends displayed. 1/

Figure 2 also shows that most of the total buy and most of the growth from 1973 to 1979 consisted of Sidewinders; this was even more so in the preceding two decades. However, the projected increases in 1982-1986 are predominantly in Sparrows; roughly three times as many Sparrows as Sidewinders will be procured in 1984-1986. This partially reflects the extent to which the inventory objectives for the various Sidewinder and Sparrow models have been met. It also indicates a shift in tactics to greater reliance on the longer-range radar missiles and less emphasis on the Sidewinder. This trend will tend to increase the cost of fulfilling overall inventory objectives, since radar missiles are more costly than infrared missiles.

Total Costs

Figure 4 displays the fraction of the total DoD procurement budget expended each year on air intercept missiles. This measures DoD's commitment to procuring these systems each year in terms of its impact on the procurement budget. The steep decline in numbers procured is mirrored by a decline in expenditures. The rise in numbers during the 1970s is also reflected in a rise in budget share. However, since numbers of missiles procured are only about one-fourth of earlier levels, the investment growth reflects dramatically higher unit costs of more sophisticated later models.

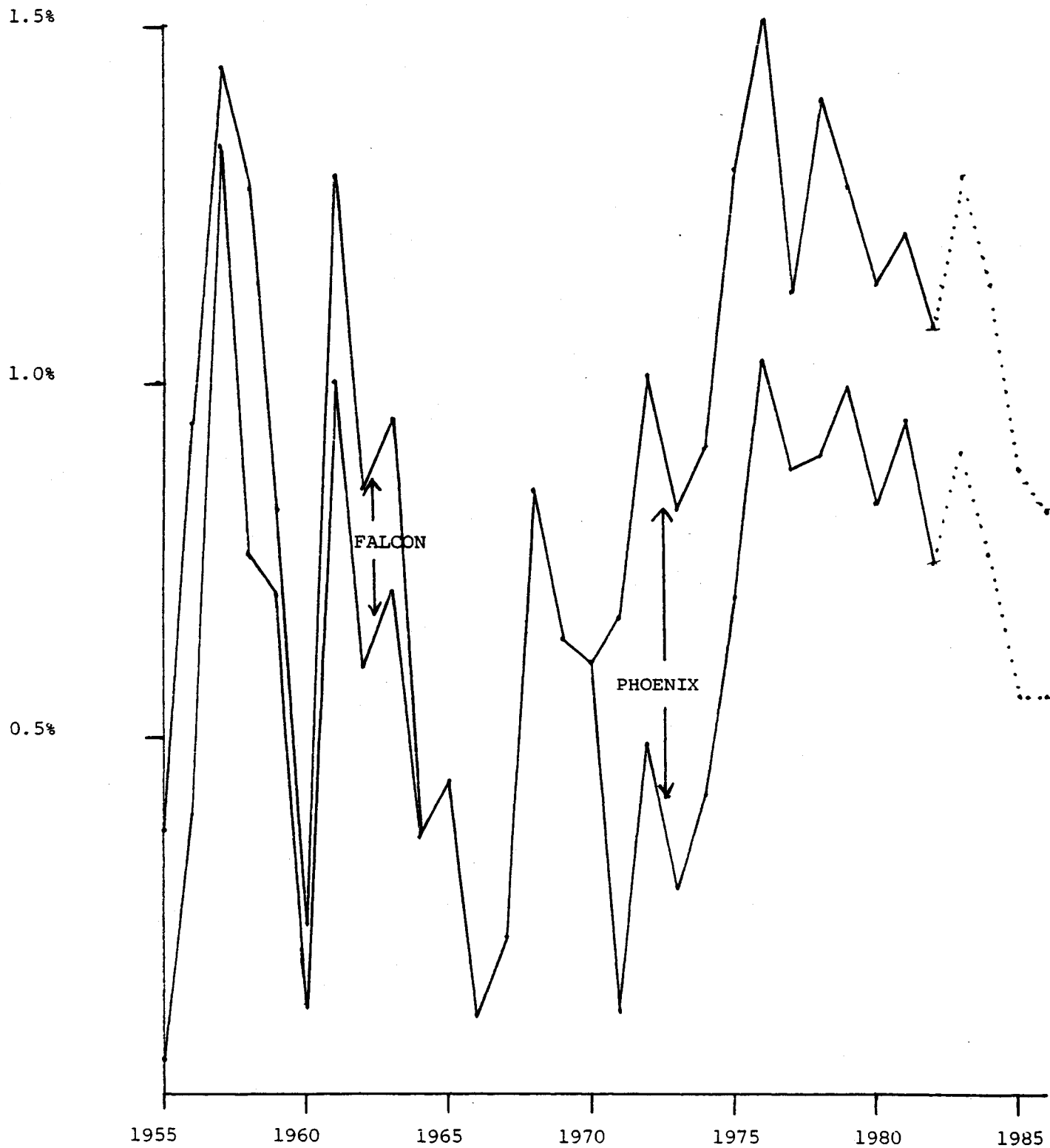
TRENDS EXHIBITED BY SIDEWINDER AND SPARROW INDIVIDUALLY

The overall trends in procurement of air intercept missiles clearly indicate that average unit costs have been increasing, and are well above what they were during the first decade of production of these systems. Furthermore, the mix of Sidewinder and Sparrow missiles is shifting away from a preponderance of

1/ Jane's Aircraft 1980-81, Jane's Weapon Systems 1980-81.

FIGURE 4. FRACTION OF THE DEFENSE DEPARTMENT PROCUREMENT

BUDGET SPENT ON AIR INTERCEPT MISSILES



Sidewinders and toward more Sparrows than Sidewinders. These trends are illuminated by examining the two missile programs separately. Doing so also permits a clearer examination of unit costs.

Sidewinder

Figure 5 shows the basic trends of the AIM-9 Sidewinder program. The bottom figure shows that the numbers procured fell rapidly in the 1960s, and then remained on the average generally unchanged until the present, with some increases in 1974-1979. The fraction of the DoD procurement budget going to this program, however, after peaking very early stayed on the average unchanged, with some overall increase in the late 1970s followed by a distinct decline. The increases in the late 1970s would appear much more substantial were the figures to show only data beginning in 1973.

The relation between the trends exhibited in these two graphs is shown in the upper graph, which exhibits average yearly unit costs in constant fiscal year 1982 dollars. The same number of missiles were bought in the early 1960s as in the late 1950s, but at a substantial reduction in budgetary impact. This is a reflection of unit cost reductions. A steady, large rise in unit costs from the early 1960s to the late 1970s is responsible for the fact that, while average expenditures have remained generally constant since 1959, numbers declined until the 1970s.

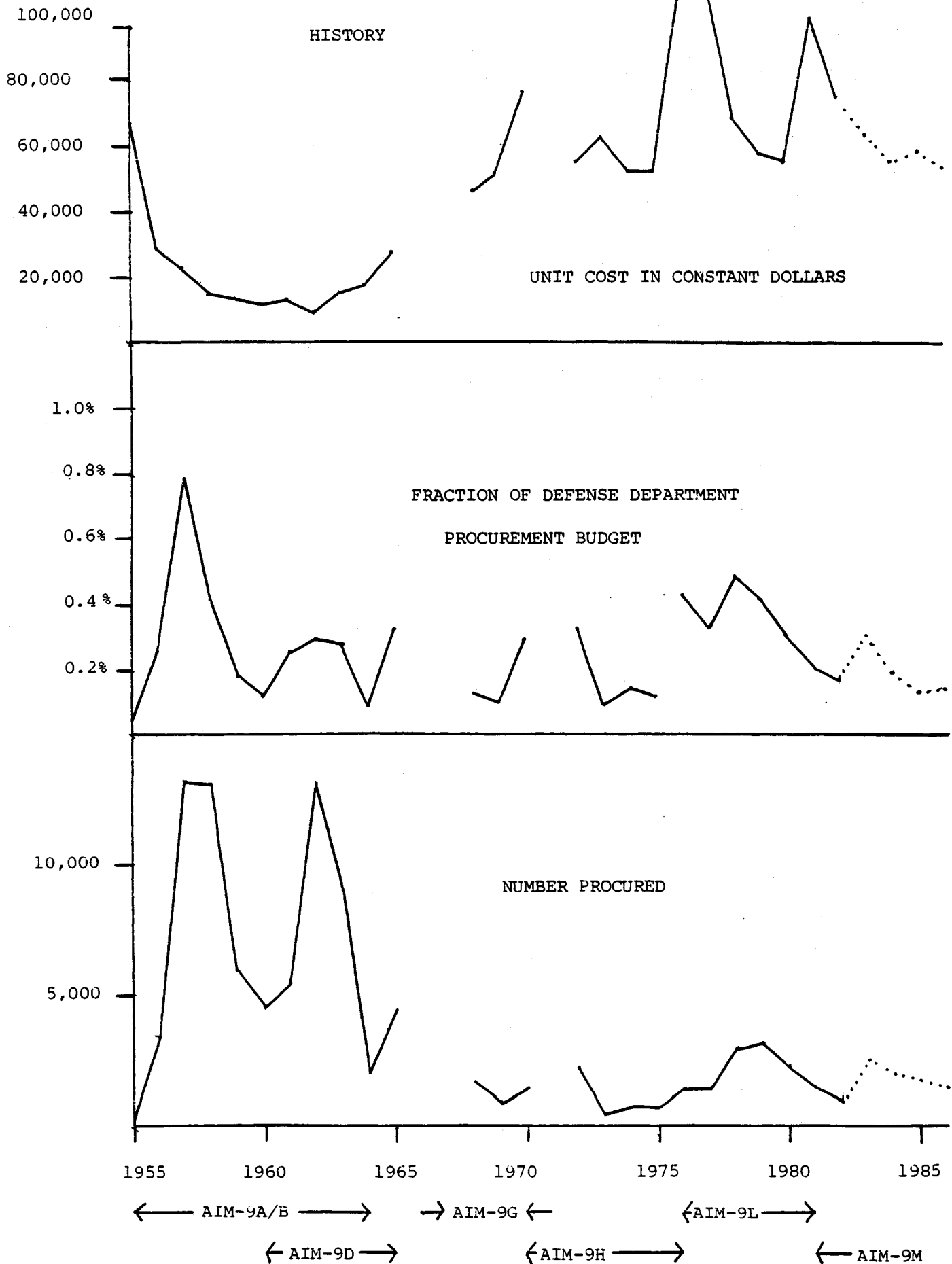
The unit cost fluctuations are explained by Figure 6. Successive introduction of new models with higher unit costs produced a steadily rising curve with "spikes" superimposed on it. As each model proceeded into production, unit costs fell.

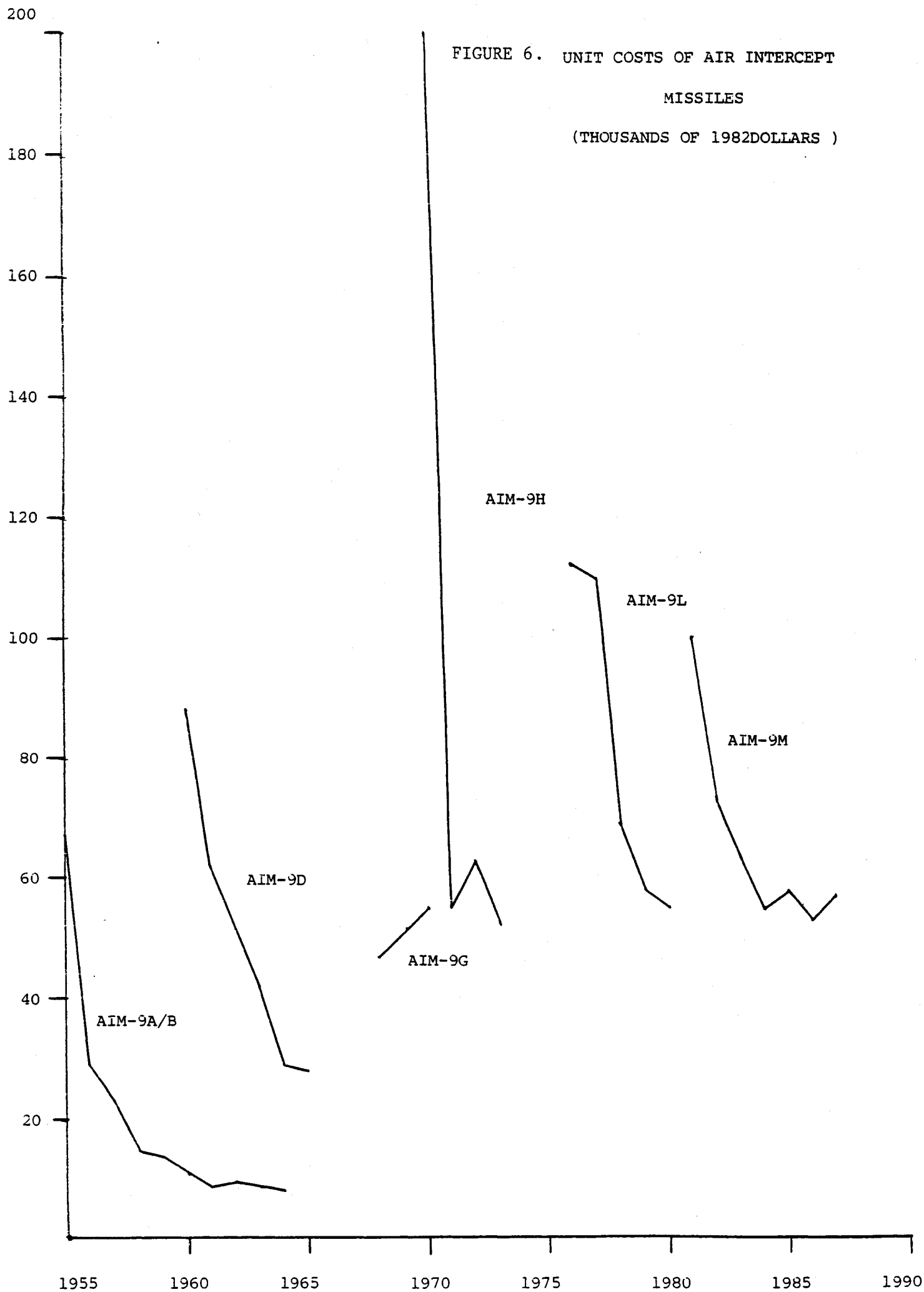
Figure 7 removes the "spikes" by displaying the average unit costs for each model plotted at the year at which that model achieved initial operational capability (IOC). The line serves only to connect the points and guide the eye. The upward trend in costs is clear: more than fivefold since the first models. The fact that the costs decrease from AIM-9L to AIM-9M indicates the potential of modern manufacturing techniques for reducing costs while improving the missile.

Sparrow

The basic trends in the history of the Sparrow are exhibited in Figure 8. Compared to the Sidewinder, the average number of

FIGURE 5. SIDEWINDER PROCUREMENT





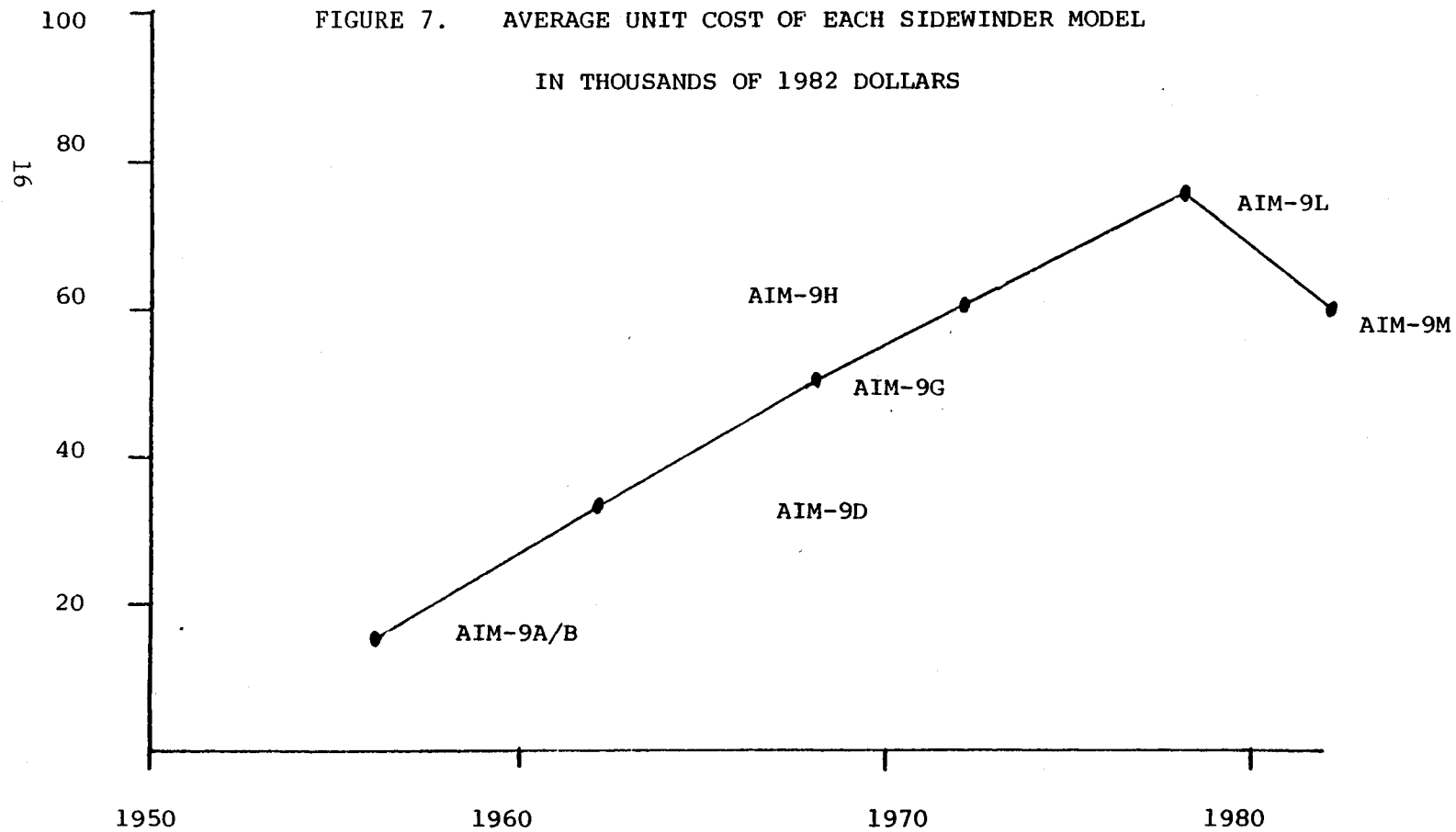
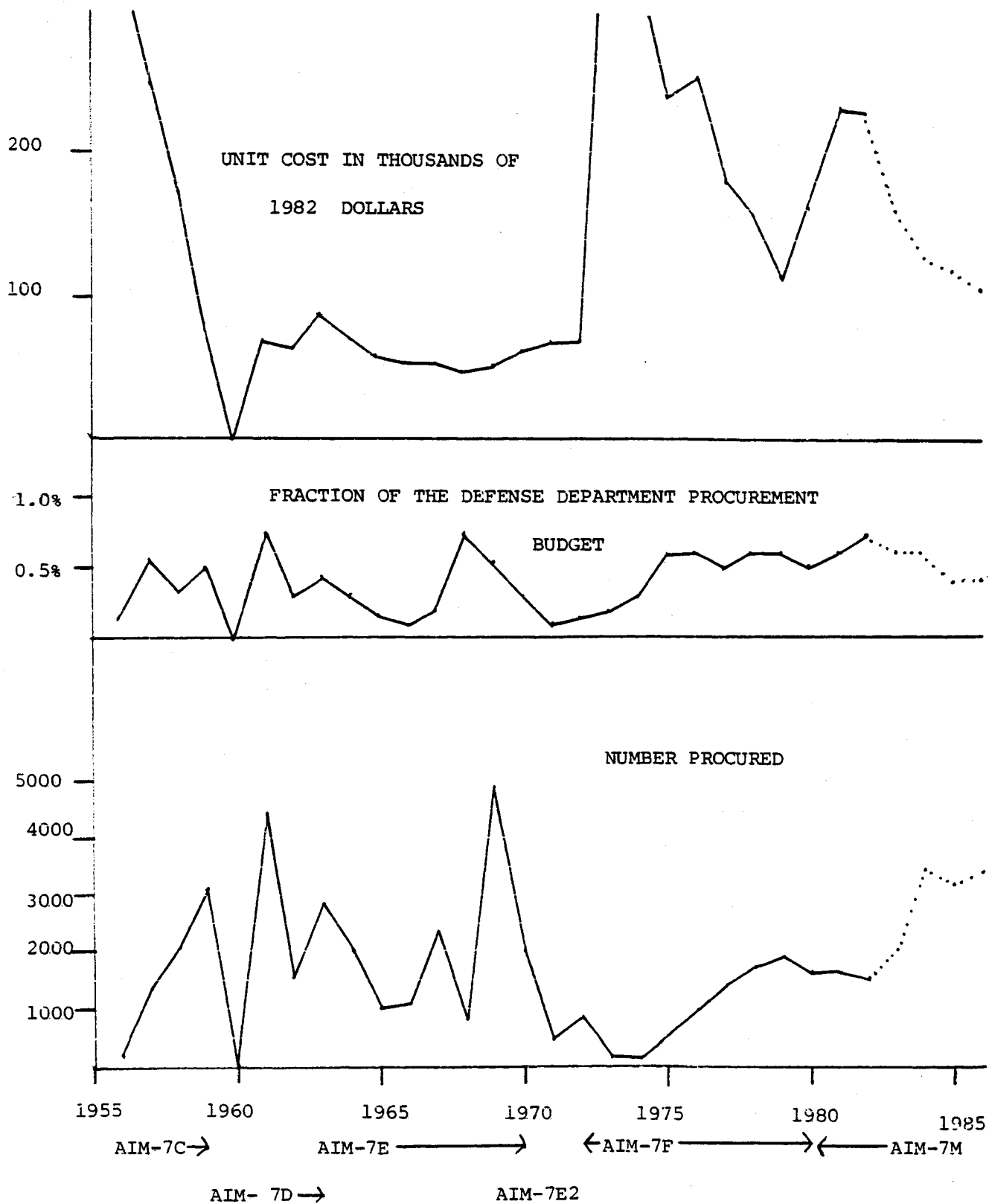


FIGURE 8. SPARROW PROCUREMENT HISTORY



Sparrows procured has remained more nearly constant over time, except for the big dip in the early 1970s. The fraction of the DoD procurement budget devoted to the Sparrow has also remained broadly constant; it is somewhat higher in recent years than it was in the early years of the program.

After the high unit costs associated with starting the Sparrow program, unit costs stayed relatively constant until the mid-1970s. The reasons for this are illustrated by Figure 9. AIM-7C, AIM-7D, AIM-7E, and AIM-7E2 all involved successive relatively small modifications. This resulted in little increase in unit cost every time a new model was introduced, equally little decrease as it entered full production, and therefore little overall variation in unit cost. This pattern is indicative of an evolution of one missile system rather than successive introductions of new models. AIM-7F, however, represented a departure as was shown in Table 3, and its introduction caused a large increase in unit costs followed by a sharp decrease, as is generally the case in the introduction of a new system. ^{2/} The introduction of AIM-7M resulted in a similar trend.

Figure 10 shows average unit costs for each model displayed at IOC. The line only serves to connect the points. In constant dollars, AIM-7F and AIM-7M cost about twice what the earlier D, E, and E2 models cost. Surprisingly, AIM-7F and AIM-7M cost about as much per unit as AIM-7C, the first model.

INTERPRETATION OF TRENDS

Changes in requirements and the incorporation of performance improvements have caused the average unit costs of AIMs to increase over the years. This was apparently accommodated during the 1960s by reducing the number of AIMs procured and in the 1970s by increasing the share of the budget devoted to procuring AIMs until it was back to the level from which it had declined during the 1960s. The major changes that have taken place have been the large rise in the cost of the Sidewinder from the early 1960s to

² Typically, when a new system is introduced, unit costs in the first year are much above average for that system. Few are produced, the line must be started, and the workers are unfamiliar with the particular product. As time goes on, the company "learns," becomes more efficient, and costs come down.

